

EFFECT OF CHIP FORMATION ON TOOL WEAR IN MACHINING OF TITANIUM

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I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

Nowadays, titanium has become an important material mainly used in engineering application because of its excellent mechanical and physical property, for example, aircraft, aero-engines, biomedical devices and components in chemical processing equipments. However, the machining of titanium is getting tougher as tool wear is a common phenomenon happened during machining operations due to the frictions and forces produced when the cutting tool is in contact with the workpiece. The kind of chips produced from the machining operation may contribute to certain tool wear and cause the cutting tool life to be lowered. So, it is necessary to find out the optimum machining parameters that produce certain chip structure formations with lowest tool wear rate. Therefore, this project gives an investigation on the effect of chip formation on tool wear in machining of Titanium. The experiments will be carried out using a Computer Numerically Controlled machine (CNC). Different value of cutting speeds and feed rates are selected in order to study and observe the kind of chip formed. The cutting speed selected in the experiment are 90, 120 and 150 m/min, while the feed rates range from 0.05 to 0.15 mm/min. Apart from that, the depth of cut is kept constant at 0.5 mm. The diameter and length of titanium used in this study are 25 mm and 200 mm respectively. The chips collected from all these machining parameters will be taken to several chip preparation processes and then examined using optical microscope. Lastly, these data will be tabulated into graphical form as to clearly show the relationship between the variables and tool wear. The result shows that the shear layer thickness of the chip is the significant parameter that influences the tool wear relatively. The higher the shear layer thickness, the lower the tool wears, and vice versa. From the experiments, the shear layer thickness is proved as affected by the cutting speed and feed rate significantly. The lowest tool wear (crater and flank wear are $7.8921\text{ }\mu\text{m}$ and $1.2162\text{ }\mu\text{m}$ respectively) was determined at shear layer thickness of $0.0123\text{ }\mu\text{m}$, which machined with cutting speeds of 162.4264 m/min and feed rate of 0.1 mm/rev .

ABSTRAK

Pada masa kini, titanium telah menjadi bahan yang penting digunakan terutamanya dalam aplikasi teknikal disebabkan oleh ciri-ciri mekanikal dan fizikal. Namun, pemesinan titanium menjadi semakin mencabar di mana kerosakan alat memotong merupakan fenomena umum yang terjadi semasa operasi pemesinan. Kerosakan ini disebabkan oleh tekanan dan daya yang dihasilkan semasa alat ini dikenakan dengan permukaan objek. Jenis cip yang dihasilkan daripada operasi pemesinan ini boleh mempengaruhi kerosakan alat memotong dan ini boleh menurunkan tempoh hayat alat memotong tersebut. Oleh sebab itu, projek ini memberikan penyelidikan tentang pengaruh cip struktur terhadap kerosakan alat memotong bagi pemesinan titanium. Eksperimen ini akan dijalankan dengan menggunakan mesin Computer Numerically Controlled (CNC). Nilai kelajuan memotong dan kadar kemasukan objek yang berbeza akan digunakan untuk mengkaji jenis cip yang terbentuk. Kelajuan memotong yang dipilih adalah 90, 120 dan 150 m/min, manakala kadar kemasukan objek adalah di antara 0.05-0.15 mm/min. Selain itu, kedalaman potong dipertahankan malar sebanyak 0.5 mm. Diameter dan panjang titanium yang digunakan dalam kajian ini adalah 25 mm x 200 mm. Cip yang dikumpulkan dari semua parameter pemesinan akan dibawa ke beberapa proses penyediaan dan kemudian memerihati dengan menggunakan mikroskop optik. Akhir sekali, data ini akan ditabulasikan dalam bentuk grafik untuk jelas menunjukkan hubungan antara pembolehubah berserta dengan analisis. Keputusan eksperimen menunjukkan bahawa ketebalan lapisan memotong merupakan satu pembolehubah yang signifikan mempengaruhi kerosakan alat memotong. Semakin kurang ketebalan lapisan memotong, semakin rendah kerosakan alat momotong, dan sebaliknya. Daripada eksperimen, ketebalan lapisan memotong ini terbukti bahawa dipengaruhi kuat oleh kelajuan memotong dan kadar kemasukan objek. Nilai kerosakan alat memotong yang paling rendah ditentukan pada ketebalan lapisan memotong sebanyak 0.0123 μm , di mana kelajuan memotong dan kadar kemasukan objek adalah 162.4264 m/minit dan 0.10 mm/pusingan.

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LIST OF SYMBOLS

| | |
|-----|-------------------|
| f | Feed rate |
| V | Cutting speed |
| p | Significant value |

LIST OF ABBREVIATIONS

| | |
|-------|---------------------------------|
| ANOVA | Analysis of Variance |
| BUE | Build Up Edge |
| CNC | Computer Numerically Controlled |

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Titanium is an important material used in a wide variety of product forms in this modern engineering world. Nevertheless, titanium and its alloys are extremely difficult to machine materials owing to several inherent properties of the metal. For instances, it has low thermal conductivity and tends to react chemically with many cutting tool materials at tool operation temperatures. Low thermal conductivity increases the temperature at the cutting edge of the tool. As this rate, on machining, the workpiece may be deformed and produce chips that different in microstructure which give effects to the tool wear. In this study, we focus on the effect of chip structure formation on tool wear in machining titanium.

1.2 PROJECT BACKGROUND

Nowadays, there are many products made from titanium in this modern industry due to its excellent properties like high strength, toughness and low mass. According to Suisman (2005), titanium is 30% stronger than steel but is nearly 50% lighter and it is 60% heavier than aluminium but twice as strong. Titanium is also nonmagnetic and possesses good heat transfer properties. It has the ability to passivate, thereby giving it a corrosion resistance to acid. Besides, the main properties such as high strength, low density, and excellent corrosion resistance have make titanium attractive for a variety of application. Examples include aircraft (high strength in combination with low density), aero-engines

(high strength, low density and good creep resistance up to about 550°C), biomedical devices (corrosion resistance and high strength) and components in chemical processing equipment (corrosion resistance).

In many titanium applications machining, it is necessary to identify the type of wear that could happen with respect to the kind of chip microstructure produced in order to increase the tool life. There are two main reasons for investigating the effect of chip structural formation on tool wear. First, the results obtained provide quantitative data to explain functional behaviors of the machined-material and second, the findings can be used as a means for process control, as well as for improving machinability of Titanium.

1.3 PROBLEM STATEMENT

Tool wear is an important parameter that must be controlled and minimized in order to increase tool life in any machining process. However, the low thermal characteristics of titanium usually produce a poor chip formation due to the heat generated cannot be conducted to environment. In this case, the cutting temperature will also increase rapidly. Moreover, the low elastic modulus of titanium property has increased more vibration during machining. Combining all these factors, titanium are said difficult to machine and produce unusual chip formation that affects the tool wears. When the tool wear is high, the tool life will be lowered and thus the replacement of new cutting tool is become quicker as compared to low tool wear. In this case, the machining cost will be increased. However, the inter-relationship between the chip structure deformation and tool wear has not been well understood and need to be investigated in this study.

1.4 PROJECT OBJECTIVE

The objectives of this project are (1) to investigate the effect of chip formation on tool wear in machining of Titanium; (2) to determine the machinery parameters that affect chip formation; and (3) to investigate the relationship between chip formation and tool wear.

1.5 SCOPE OF THE PROJECT

This study mainly focuses on machining of titanium, which will be carried out in a CNC turning center. The experiment procedures will be designed by the Design of Experiment (DOE) method using STATISTICA software. It will rearrange the order of turning operation in different cutting speeds and feed rates in order to minimize the error. Machining parameters selected in this study, cutting speeds and feed rates will be varied up to few levels. Constant depth of cut is chosen based on the literature and finding. The cutting speed range from 77.5736, 90, 120, 150 and 162.4264 m/min whereas the feed rates used in the experiment are 0.029289, 0.05, 0.10, 0.15 and 0.170711 mm/min. The chips will be collected from each machining parameter in turning process and undergo several chip specimen preparation process such as hot mounting, grinding, polishing and etching.

Next, the chips microstructure was observed by using optical microscope and integrated software. All the experimented data will be collected for further analysis. Finally, a tool wear curve was developed with respect to chip microstructure from the results obtained by using Excel workbook.

1.6 ORGANIZATION OF THESIS

This study is delegated into five chapters. In the first chapter, the introduction of the project title is discussed and the problem statements, objectives, scope of project are reviewed in order to list out the tasks and act as a guideline for this study.

In the second chapter, it consists of detailed literature review of machining titanium and tool wear. At the beginning of this chapter, some of the basic information about the titanium is discussed. Next, the operation of CNC turning is reviewed together with cutting tools, cutting fluids and turning parameters which play an important role in determining the machining efficiency and result. Moreover, this chapter continues with chip formation study and tool wears which is inter-related with the project research. Lastly, the related previous research about this study is briefly discussed.

Next chapter consists of the methodology which is used to conduct the whole research experiment from the starting until the study is completed. Starting of this chapter, an overall project flow chart is designed in order to act as guideline for task sequences. In addition, the information about the materials used to complete the study is briefly discussed.

In the forth chapter, the results obtained from the experiment will be discussed. Several graphs will be made to preview the relationship between the chip formation and tool wear, which is resulting from different machining parameters, namely cutting speed and feed rate. At the end of this chapter, some of the sources of errors that affect the experiment outcomes are briefly discussed.

The final chapter consists of the conclusions of the study together with the project summary, project findings and further recommendations to improve the study in the future.

1.7 CONCLUSION

In Chapter 1, the project background, problem statement, objectives and scope of the project related to the boundary of my study was presented to avoid any unwanted deviation from the project title. This chapter was thereby acted as guidelines for the whole project. The relationship between chip structure formation and tool wear, machining parameters that influence chip formation and tool wear relationship were determined at the end of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discussed about the literature review of the chip microstructure on tool wear in machining of titanium. Starting of this review, titanium machining from aspects of machining parameters, cutting tool, cutting fluid, chip formation and tool wear are briefly discussed. Next, an overviews of the previous study related to this title is discussed.

2.2 TITANIUM MACHINABILITY

Titanium is a chemical element with the symbol Ti and atomic number 22. Commonly, it has a strong, lustrous, corrosion-resistant metallic element with low density, which covered in silver color. In most of the application, titanium can be alloyed with many elements to produce strong and lightweight property such as vanadium, aluminium, iron and so on. The specific weight of titanium is about two thirds that of steel and about 60% higher than aluminium. In term of tensile and sheet stiffness, titanium has fall between steel and aluminium. Moreover, its Young's Modulus and ultimate strength are ranging from 100-110GPa and 300MPa respectively. The mechanical properties of pure titanium can be shown in the Appendix A.

In any machining operation, titanium has a tendency to gall, and its chips can weld to the cutting edges of the tool and this will lead to tool wear begins. In addition, the titanium's low modulus of elasticity can caused slender workpieces to deflect more than

steel. In consequence, this will arise to cutting problems like chatter, tool contact and holding tolerances, which greatly affect the workpiece surface finish and tool wear.

However, it is often to produce an unusual chip microstructure with titanium due to the nature of the metal and generation of high temperature during machining process. Lastly, the tool wear and tool life depend greatly on the kind of chip microstructure formation which is influenced by the machining parameters.

2.3 MACHINING: COMPUTER NUMERICALLY CONTROLLED (CNC) TURNING PROCESS

Turning is best describes as a material removal process, which is used to create rotational part by cutting away unwanted part of material. Basically, the workpiece is secured to fixture, which is attached to the turning machine and allows rotating at high speed. Next, the cutting tool feeds into the rotating workpiece and cuts away the unwanted portion of material in the form of small chips to create the desired shape. Turning can be performed either manually or by computer through numerical controlled programming. A typical CNC machine is shown in Figure 2.1.



Figure 2.1: Computer Numerically Controlled (CNC) machine.

In the CNC turning process, a piece of material is rotated on the lathe and a cutting tool is traversed along two axis of motion, either transversely or longitudinally. The lathe holds the workpiece in cylindrical shape between two rigid supports (a.k.a chuck) that revolves about the centre line of the lathe. The spindle carrying the work is rotated whilst a cutting tool, which is supported in a tool post, is made to travel in a certain direction depending on the type of surface required. For example, a cylindrical surface is shaped when the tool moves parallel to the axis of the motion. The whole process is continued until the required depth and dimension is achieved. According to one's needs and specification, turning can also be done from inside-to-outside or vice versa.

Figure 2.2 shows the schematic diagram of typical turning process. The spindle or rotation speed, which enables control of tool motion, can be adjusted using a computer programming. Turning tool moves in one direction which is call feed direction. Parts that are too large to balance and cause difficulty in rotating around one center point, can be worked on a machining center featuring a U axis. The turning length is about 1000 mm between centers and has a drive power and speed range up to 46 kW and 3000 revolution per minute respectively.

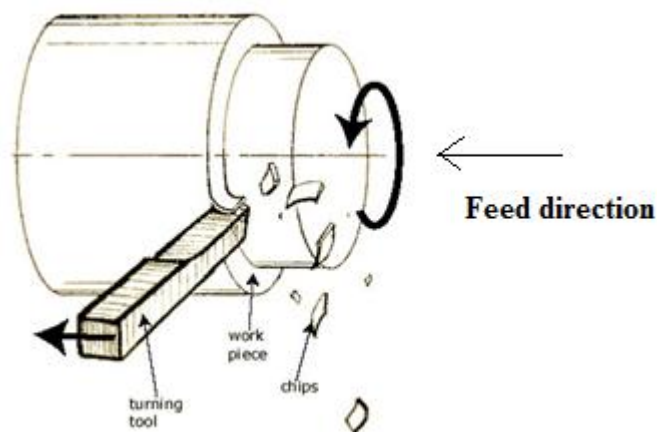


Figure 2.2: Schematic diagram of typical turning process.

According to the diagram above, it is necessary to identify the appropriate spindle rotational speed before running the turning process. Different materials would have different allowable cutting speed range. The relationship between surface speeds so called cutting speed and spindle rotational speed can be best described as:

$$V = \pi DN \quad (1)$$

Where,

V= Cutting speed, (m/min)

D= Diameter of bar (m)

N= Spindle rotational speed (RPM)

The cutting tool is used until the required depth and dimension is achieved. Turning can be on both side, inside or outside as per the need and specifications. The rotation occurs at the turning center that enables control of tool motion through computer programs that use numeric data.

CNC turning process allows the materials to be cut into various shapes ranging from plain surface, taper ends, contour and fillet to radius profiles as well as threaded surfaces. These cut and turned metal pieces are then used to create shafts, rods, hubs, bushes, pulley and etc. CNC turning machines are able to deliver components at a faster production rate with optimum manufacturing accuracy.

2.4 TURNING PARAMETER

In turning process, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based upon the workpiece material, tool size, and tool material. These parameters are important because it will directly affecting the output and also the performance of work. So, the turning parameters that can affect the process are shown in the Table 2.1.

Table 2.1: Parameter in turning process.

| Parameter | Definition |
|---------------------|---|
| Cutting speed | The speed of the workpiece surface relative to the edge of the cutting tool during a cut, measured in surface feet per minute (SFM). |
| Feed rate | The speed of the cutting tool relative to the workpiece as the tool makes a cut, measured in millimeter per revolution (RPM). |
| Spindle speed | The rotational speed of the workpiece in revolution per minute (RPM). The spindle speed is equal to the cutting speed divided by the circumference of the workpiece where the cut is being made. |
| Axial depth of cut | The depth of the tool along the axis of the workpiece as it makes a cut, as in a facing operation. |
| Radial depth of cut | The depth of the tool along the radius of the workpiece as it makes a cut, as in a turning or boring operation. A large radial depth of cut will require low feed rate, or else it will result in a high load on the tool and reduce the tool life. |

2.5 CUTTING TOOLS

Cutting tool is one of the most important components in the machining process, in which its performance determines the efficiency of the operation. In particular, consideration should be given not only to the selection of the cutting tool material but also to the cutting tool angles required to machine titanium properly.

Generally, the properties possessed by each of these materials are different and the application of each depends on the material being machined and the condition of the machine. Different material property would require different cutting tool to shape it into desire dimension. Generally, these tool bits should possess the following properties: